Chapter 1

Scientific Method
- Make observations
- Make a hypothesis
- Has to be tested
- Make prediction assuming hypothesis is true
- Carry out experiments
- Mathematics is the tool to understand and predict the natural world

Scientific Method and Meteorology
- Atmosphere obeys laws of physics and chemistry
- Instruments allow us to quantify the state of the atmosphere
- Thermometer
- Hygrometer
- How much humidity/moisture in air
- Barometer
- Air pressure
- Anemometer
- Wind speed/wind direction
- Mathematics can project current conditions into the future
- Uses computer models to help with calculating

Weather and Climate
- Weather describes state of the atmosphere at any given time
- Temperature
- Air Pressure
- Humidity
- Cloud Cover
- Precipitation
- Visibility
- WInd Velocity

Chapter 1 (cont)

- Climate describes average atmospheric conditions over at least 30 years
- Includes extremes
- The frequency of extremes help differentiate between locations with similar averages

Meteorology
- Meteorologica
- Book on natural philosophy by Aristotle in 340 BC
- How meteorology got its name
- Study of the atmosphere and its phenomena
- Began with the invention of weather instruments (1450--1650)
- Quantified the atmosphere
- Allows for the prediction of what the atmosphere will do
- Telegraph (1843)
- Allowed for the transmission of current weather conditions across vast areas
- Weather Map Analyses (1869)
- Visual snapshot of current state of the atmosphere
- Understanding of Air Masses adn fronts (1920)
- Key weather features that drive world weather patterns
- Daily weather ballon launches (1940s)

Chapter 1 (cont)

- These radiosondes provide 3D view of the atmosphere
- Numerical Weather Prediction (NWP)
- Solving the mathematical laws of physics/chemistry at high speeds

Remote Sensing of the Atmosphere
- Weather Radar (1940s)
- Detects precipitation targets from over 100 miles away
- Doppler Weather Radar (1990s)
- Detects precipitation targets and their motion
- “Sees” the wind
- Dual Pole Doppler Weather Radar (2000s)
- Distinguishes between rain, snow, hail, and bugs
- Weather Satellites (1960s)
- Reveal weather features produced by cloud patterns
- Can supply NWP with data from every location on Earth
- Most Common Type of Satellite
- Geostationary
- Orbits the Earth at the same speed the Earth spins
- GOES 16 and 17 Satellites
- Best View of the US

Chapter 1 (cont)

- Centered over the Equator (0º Latitude) and 75º W | 137ºW Longitude
- 22,300 Miles

Latitude
- the angle made between center of Earth and a point on surface using the Equator as the reference line
- North Pole = 90º N Latitude | South Pole = 90ºS Latitude
- Most of the US is between 30ºN and 50ºN Latitude

Longitude
- the angle made between center of Earth and a point on surface using the Prime Meridian as the reference line
- Runs from N Pole to S Pole through Greenwich, England
- Most of the US lies between 70ºW and 125ºW Longitude

Most Common Type of Storm System
- Middle-Latitude Cyclonic Storm System
- Extratropical Cyclone
- Cyclone=area of low pressure
- Anticyclones=are of high pressure

Depiction of Winds
- Wind is defined from the direction it is blowing

Chapter 1 (cont)

- Represented by a line - *wind barb* - drawn parallel to wind
- Points in direction from which the wind is blowing
- Speed is represented by wind flags
- Full flag = 10 knots
- Half flag = 5 knots

Wind Flow

- Counterclockwise and inward around lows
- Clockwise and outward around highs

In Southern hemisphere…

- Clockwise/inward around lows
- Counterclockwise/outward around highs
- Wind does not cycle around the equator
- No hurricanes but tornados can still happen

Vertical Wind Flow Around High and Lows

- Air converges and rises in the center of low pressure (cyclone)
- Clouds/precipitation
- Air diverges and sinks in the center of high pressure (anticyclone)
- Clear skies

Weather Fronts

- Cold front
- Boundary that separates colder air from warmer air
- When colder air advances and replaces warmer air

Chapter 1 (cont)

- Warm front
- Boundary that separates colder air from warmer air
- When warmer air advances and replaces colder air
- Occluded front
- When cold front merges with warm front
- All fronts are usually but not always associated with rising air, clouds, and precipitation

Impacts of Weather and Climate

- Weather dictates the clothes we wear on any given day
- Climate dictates the clothes we have in our wardrobe
- Climate dictates the type of crops we can grow
- Weather dictates whether the crops can be harvested

When Weather is Not What it Seems

- Wind Chill
- Body perceives a lower temperature than it really is
- Hypothermia
- Frostbite
- Heat Index
- Body perceives a higher temperature than it really is
- Hyperthermia
- Heat Exhaustion or Heatstroke

Other Biological Impacts

Chapter 1 (cont)

- Rapid pressure falls/rising humidity
- Can induce expansion of joints and cause joint pain
- Wind flowing downhill heats up
- Chinook winds/ Santa Ana
- Incidence of depression increases

Economical Impacts of Weather

- Warm winters = lower heating bills
- Beware of unusual winter severe weather outbreaks
- Cold winters = higher heating bills
- Severe Artic air cold snaps can threaten human lives/infrastructure damage/massive crop losses
- Heat Waves and Drought
- Crops losses
- Wildfires increase
- #1 in weather-related fatalities

Climate Change Bringing More Extremes

- Heat waves and drought increasing
- Flooding events increasing
- Hurricane intensity increasing

Other Weather Hazards

- Severe Thunderstorms
- 50 knot (58 mph) winds
- 1-in hail
- Tornado

Chapter 1 (cont)

- It has to fulfill one condition to be considered
- Flash Flooding
- Slow-moving thunderstorms
- “Training” storms
- Downburst winds
- Macroburst- greater than 4 km (2.5 mi) in diameter
- Microburst - less than 4 km in diameter
- Both produce Wind Shear
- Change in wind speed/direction over short distance

Who Studies This?

- Meteorologist
- Professionaly trained, college degree in atmospheric science
- Weathercaster
- Good communicator of weather information

Weather Business is Expanding

- Private Meteorological
- App Development
- Forensic services

Fundamentals of Meteorology

The atmosphere is a mixture of gases

- Nitrogen
- Oxygen
- Argon
- Water Vapor (highly variable)
- Carbon Dioxide (generally increasing)

Chapter 1 (cont)

Most of the gases are near the surface
- Air gets “thinner” as you go up
99% of atmosphere is within 19 mi of teh surface
- Blocks deadly solar radiation from reaching the surface

The First Atmosphere
- 4.6 BYA the atmosphere was mostly hydrogen and helium
- Some methane and ammonia thrown in
- Hydrogen and helium escaped into space
- Earth’s gravity not strong enough

The Second Atmosphere
- Outgassing from Earth’s hot interior (volcanoes)
- Mostly water vapor (80%), carbon dioxide (10%), and some nitrogen
- Water vapor “condensed” into clouds with rain lasting 1000s of years
- Combined with asteroid/comet collisions that formed the oceans

Water Vapor Levels in Atmosphere Drop
- Most of the water vapor converted to liquid water
- Atmosphere now just a few % water vapor

CO2 Levels Drop
- CO2 readily dissolves in water

Chapter 1 (cont)

- Combined with chemicals in the ocean to form limestone

N2 Levels Increase
- Nitrogen is not very chemically reactive
- Once in the atmosphere, tends to stay

O2
- Solar radiation splits water vapor into hydrogen and oxygen
- Hydrogen escaped into space
- Oxygen left behind
- 2.4 BYA, something wonderful happens
- Cyanobacteria (blue-green algae) produce O2 from photosynthesis
- Earth begins to cool
- O2 combines with O to form O3 (ozone)
- O3 in upper atmosphere absorbs incoming radiation cooling the Earth
- Methane breaks down in the presence of O2
- Warming effect of methane weakens
- Earth becomes very cold
- Cyanobacteria proliferate around the world removing CO2 from atmosphere
- Warming effect of carbon dioxide weakens

First Mass Extinction
- Earth gets covered in ice
- Frigid Earth no longer supporting life
- No O2 being produced

Chapter 1 (cont)

- O2 is highly reactive/combines with other elements to form rocks
- O2 levels drop worldwide

Life Gets a Second Chance
-- Outgassing increases water vapor/carbon dioxide (volcanoes)
- H2O and CO2 are warming gases
- Takes over a billion years for new photosynthesizing life to reappear
- After another 1/2 billion years, O2 levels are where they are today

Water Vapor
- 0% to 4% of the atmosphere
- Always invisible
- Become visible when vapor molecules “jump” on each other to form droplets or ice crystals
- Condensation form droplets
- Deposition form ice crystals
- Evaporation is when liquid turns to gas
- Water is only substance that can exist in all 3 phases at normal temperature/pressure

Characteristics
- Greenhouse Gas
- Very effective at absorbing outgoing radiation emitted by Earth

Chapter 1 (cont)

- Re-emits some of this energy back keeping the Earth warmer

Carbon Dioxide
- Greenhouse Gas
- Comes from the decay of vegetation
- Volcanic eruptions
- Burning of coal, oil, natural gas (fossil fuels)
- Removed by photosynthesis of land and ocean plants
- CO2 gets stored in roots, branches, and leaves
- Chemical weathering of rocks
- CO2 dissolves in rainwater
- Forms carbonic acid
- Combines with minerals in rocks and becomes part of the rock
- Dissolves in Ocean water
- Used by sea critters to make shells
- Eventually sinks to bottom of the sea

Vertical Structure of the Atmosphere
Air is compressible
- Gravity pulls most -but not all- air molecules near the surface
- Air Density = # of air molecules in a given volume
- Mass/volume
Air Density and Air Pressure

Chapter 1 (cont)

- Force exerted by air molecules against a surface
- Same thing as the weight of the air above you
- At sea level, air weighs 14.7 lbs per square inch

Measuring Air Pressure

- 14.7 lbs/in2
- 1013.25 millibars (mb)
- 29.92 in Hg

Atmosphere is Very Thin

- Half of the air molecules is below 5.5 km (18,000 ft)
- 99.9% is below 50 km (160,000 ft)

Layers of the Atmosphere

- Atmospheric layers are defined by how the temperature changes with height
- Lapse Rate= rate at which temperature decreases with height
- In lower atmosphere, lapse rate = 6.5ºC per km (3.6ºF per 1000 ft)
- Temperature can INCREASE with height
- This is called temperature inversion
- Lapse rate is negative
- Troposphere
- Stratosphere
- Mesosphere
- Thermosphere
- Ionosphere
- Lower part of the Thermosphere

Chapter 1 (cont)

- Solar energy strips electrons from N2 and O2 causing them to glow

Northern and Southern Lights

- Aurora Borealis - N. Lights
- Aurora Australis - S. Lights

Chapter 2

- Energy
- The ability to do “work”: when an object moves
- Kinetic Energy
- Energy of motion- translational, rotational and vibrational
- Potential Energy
- Energy that can convert to kinetic energy
- Water that is behind a dam
- Object suspended in the sky
- Temperature
- Average kinetic energy of atoms in a substance
- Some move fast, others not so fast
- Average motion = temperature
- When molecules move, rotate, and/or vibrate, we say that the object has a temperature
- When air molecules move slowly, they crowd together
- It is cold and air is dense

Chapter 2 (cont)

- When air molecules move quickly, they spread out
- We say it is warm and the air is less dense
- Internal Energy (Heat energy)
- The total kinetic and potential energy of all atoms or molecules
- Heat
- Heat is the transfer of energy from warmer objects to cooler ones
- The bigger the temperature difference, the faster the energy transfer
- Know how to convert temperature scales

Temperature Measurements
- Important Temperature Values
- Ice point
- Ice melts, water freezes
- 32ºF, 0ºC, 273.15K
- Steam point
- Water boils
- 212ºF, 100ºC, 373.15 K

Types of Heat Energy
- Sensible Heat
- Heat energy that can be absorbed or released by a substance that results in a change of temperature
- Latent Heat

Chapter 2 (cont)

- Heat energy that is absorbed or released by a substance when the substance undergoes a phase change
- Temperature of substance does not change
- Let ice at 32ºF absorb heat energy
- Ice melts, but its temp remains at 32ºF
- Only after the ice completely melts will the water warm up
- If water freezes, it releases the same heat it took to cause it to melt in the first place but water temp does not change
- The surrounding air does warm
- How does heat energy get transferred?
- Conduction
- Heat transfer by contact of one substance with another
- Energy gets transferred from one molecule to the next
- Some materials transfer heat better than others
- Metals are good conductors
- Fiberglass, cork, wood, cloth, glass, water are poor conductors
- Air is a poor conductor of heat
- Heat (Thermal) Conductivity

Chapter 2 (cont)

- Measure of how well a substance transfers heat energy
Why Temperature Decreases with Height
- Atmosphere is mostly “transparent” to incoming sunlight
- Sun does not heat air directly
- Atmosphere can be heated by conduction
- Ground absorbs sunlight
- Air in contact with ground gets heated
- Heat energy does not get conducted to higher altitudes very well
How Does Heat Energy Get Transferred?
- Convection
- Heat transferred due to the movement of a substance from one place to another
- Much more efficient than conduction
- Moving heat energy vertically and horizontally
- Convection - vertical air motions, also called thermals
- Advection - horizontal air motions
- Radiation (Electromagnetic Radiation or Radiant Energy)
- The only heat transfer possible in a vacuum
- Can also transfer heat in air or water

Chapter 2 (cont)

- Energy is carried by photon particles defined by their wavelength
- nm=nanometer= billionth of a meter
- μm=micrometer or micron= millionth of a meter
Radiation Laws
- Facts
- All objects above Absolute Zero radiate (emit) energy at ALL wavelengths
- 0K = -273.15ºC= -459.67ºF
- Even in interstellar space, the temperature is between 2.7K and 5K
- Total Radiation emitted = Sum of energy emitted from every wavelength
- Total Energy emitted by every square meter of an object is given by the Stefan-Boltzmann Law
- E=o x T^4 (results is in Watts per square meter, W/m_2 or W m^-2
- Watts=Joules per second, J/s or Js^-1
- Temperature has to be in Kelvins
- o is constant variable
- Hot objects emit more radiation than cooler objects
- There is one wavelength (λ_max) that an object will emit most of its radiation
- Wien’s Displacement Law

Chapter 2 (cont)

- λ_max = 2897/T (answer is in μm)
- T must be expressed in Kelvin
- Stefan-Boltzmann and Wien’s Law
- Only valid if object is a blackbody object
- An object that is a perfect absorber and perfect emitter of radiation
- Absorbs all radiation that strikes it and then emits max possible radiation
- Absorption and Emission
- If an object absorbs radiation, it must also emit radiation
- If absorption is greater than emission, object heats up
- If absorption is less than emission, object cools down
- If absorption = emission, object’s temperature remains the same
- Radiative Equilibrium Temperature
- Absorption
- Gas molecules are picky about which type of radiation they will absorb
- Selective Absorbers
- Some will only eat shortwave radiation
- Shortwave is less than 1.4μm
- Some will only eat longwave radiation

Chapter 2 (cont)

- Longwave is greater than 1.4 μm
- Some will eat both or neither
- Air is mostly transparent to incoming solar radiation
- Air is not transparent to outgoing terrestrial radiation
- Some gases absorb Earth’s outgoing radiation and then reemit some of it back to the surface
Main Greenhouse Gases
- Water Vapor
- Carbon Dioxide
- Methane
- Nitrous Oxide
- Ozone
Benefit of the Greenhouse Effect
- Average temperature of the Earth is 59ªF
- Without greenhouse gases, it would be 0ºF
What Else Happens to Radiation When it Enters the Atmosphere?
- Transmission
- Radiation passing through air molecules without interacting with any of them
- About 55% of incoming solar radiation is transmitted
- Reflection
- Radiation that bounces off an object at the same angle object, and it leaves at the same intensity

Chapter 2 (cont)

- Scattering
- Produces a large number of rays traveling in all different directions
- Scattered radiation is weaker than what originally hit the object
- Gasses scatter solar radiation preferentially
- Some wavelengths are scattered better
- Atmospheric gases - mostly N2 and O2 scatter blue/violet more effectively than reds/oranges
- Violet is scattered best
- Blue is at higher intensity level than violet
- Human eye detects blue better than violet
- When Sun is on horizon, light travels through a lot more atmosphere than when Sun is overhead

Quantifying Reflected Radiation
- Albedo
- Percentage of radiation reflected by an object
- Average albedo for Earth is about 30 percent
- Average albedo for the Moon is about 7 to 12 percent
- A perfect reflector would have an albedo of 100%
- Saturn's moon Enceladus has an albedo of almost 100%

What Causes Temperature Differences?

Chapter 2 (cont)

- Solar Radiation Intensity largely determines temperature
- High solar radiation intensity-=tropical areas
- Low solar radiation intensity = arctic/antarctic area
- Solar Radiation Intensity = Power/Area
- Partly determined by height of Sun above horizon
- Midday sun always high in the sky in the Tropics
- Midday sun never high in the sky in Arctic/Antarctic areas

Important Dates to Remember
- Solstices and Equinoxes
- Summer solstice: June 21 or 22
- At solar noon, sun's rays are vertical at Tropic of Cancer 23 1/2º N Latitude
- Longest day
- WInter solstice: December 21 or 22
- Vertical rays at Tropic of Capricorn: 23 1/2ºS Latitude
- Shortest day
- Autumnal equinox: September 22 or 23
- Vertical rays at the equator
- day and night are equal

Chapter 2 (cont)

- Vernal (spring) equinox: March 21 or 22
- Vertical rays at the equator
- 12 hour days/nights everywhere

Solar Noon
- The time when the sun reaches its highest point in the sky
- halfway between sunrise and sunset

Solar Declination
- The latitude where Sun is directly overhead at solar noon
- Can only be in the tropics on any given day

Solar Elevation Angle (SEA)
- Angle the Sun makes with horizon at any time
- When sun is on horizon, SEA is 0º
- Halfway up into the sky, the SEA is 45º
- If sun is directly overhead, SEA is 90º

Solar Noon Angle (SNA)
- Angle the Sun makes with the horizon at solar noon
- Sun will be at its highest point in the sky at solar noon on any given day
- Sun will be at absolute highest point in the sky at solar noon on the first day of summer

Chapter 2 (cont)

- Sun will be at its absolute lowest point in the sky at solar noon on the first day of winter

Procedure to Finding the Solar Noon Angle
1. Where is the Solar Declination
2. Calculate latitude difference to the SD
3. Subtract this difference between 90º

Chapter 3

Temperature Definitions
- Daily Mean
- Average of the 24 hourly-temperature readings
- Add high | low and divide by two
- Daily Temperature Range
- Difference between high and low
- Monthly Mean
- Average of daily means for the month
- Annual Mean
- Average of the 12 monthly-means for the year
- Annual Temperature Range
- Difference between highest and lowest monthly mean

Controls of Temperature
Anything that determines the temperature of a location is called "Control of Temperature"
- **#1 Control:** Amount of Solar Radiation received

Chapter 3 (cont)

- Solar Angle
- Length of daylight
- Latitude determines solar angle and day length
- Areas on same latitude have the same solar angles and number of daylight hours on any given day
- So latitude is no. 1 control
- Differential heating of land and water
- Land and water do not heat up/cool down at the same rate
- Water requires 3-5x as much energy than land to heat up to the same temperature
- Geographic position
- If prevailing winds blow from sea to land (windward coast), temperatures will not change much
- Tend to have a small annual temperature range
- If prevailing winds blow from land to sea (leeward coast), temperatures will fluctuate much more
- Tend to have a larger annual temperature range
- Ocean currents
- Warm Gulf Stream
- “River” of warm water transports heat to northern latitudes
- Western Europe is much milder than it should be
- Effects of warm ocean currents
- Palm Trees in England and Ireland

Chapter 3 (cont)

- Effects of Cold/Warm Ocean Currents
- Poleward currents bring warmer conditions
- Equatorward current bring cooler conditions
- Another Effect of Cold Ocean Currents
- Land is pretty dry
- Ex. Atacama Desert is the driest place on Earth due to the cold Peru Ocean Current
- Elevation
- Temperatures usually decrease with altitude in the troposphere
- Atmosphere is mostly transparent to solar radiation but the ground absorbs almost all radiation that hits it
- Air in contact with ground (conduction) heats up the most
- Atmosphere is heated from bottom up
- Cloud cover
- Clouds (or water vapor) lower surface temperatures during the day
- Clouds (or water vapor) increase surface temperatures at night
- Albedo variations
- High albedo reduces surface temperature
- Low albedo increases surface temperature

Consequences of Being Next to Large Body of Water

Chapter 3 (cont)

- Inland Winnipeg and Coastal Vancouver
- Cities are located at a similar latitude
- Vancouver has a milder climate
- Temperatures in S. hemisphere do not fluctuate as much
- S. Hemisphere is the “water hemisphere”
- Water moderates temperatures

Minimum and Maximum Temperatures of the Day/Year

- Delay in reaching high temperature: Lag of the Maximum
- Also applies to the seasons

Urban Heat Island Effect

- Interior sections of cities tend to be warmer than surrounding rural areas

Temperature Measurements

- Mechanical thermometer
- Liquid in glass | expands when heated, contracts when cooled
- Maximum thermometer - mercury
- Minimum thermometer - alcohol
- Thermograph
- Two metals in the strip will expand/contract differently depending on the temperature

Chapter 3 (cont)

- Electrical thermometers
- Thermistor measures the resistance to electric current
- Provides accurate temperature reading even when temperature changes quickly (radiosondes)
- Instrument shelters
- White box
- Louvered sides (slits in the housing unit)
- Over grass and away from buildings
- 1/5m (5 feet) above ground

Crop Protection Against the Cold

- Frost/Freeze Prevention
- Water sprinklers add heat from the latent heat of fusion when the water freezes
- Air mixing uses wind machines to mix warm and cool air
- Orchard heaters produce the most successful results, but fuel cost and pollution can be significant

Heat Stress and Wind Chill: Indices of Human Discomfort

- Heat Stress Index: Temperature the body perceives when you include effects of humidity
- Evaporation of sweat is reduced when humidity is high

Chapter 3 (cont)

- Apparent Temperature: temperature a person perceives
- Wind Chill Index: Temperature the body perceives when you include effects of wind
- Cold, dry air will evaporate moisture from the body
- Wind will blow away isolating air layer that surrounds the body
Temperature and the Economy
- Heating Degree Days
- Gives a sense of how often one needs to heat a building
- Assumption: Heating not required when daily mean temperature is ≥65ºF, then there is zero heating degree days
- For each degree the mean temperature < 65ºF, this is counted as one Heating Degree Day
- Cooling Degree Days
- Cooling not required when daily mean temperature is 65ºF or lower
- Each degree of temperature > 65ºF is counted as one Cooling Degree Day
- Heating/Cooling Degree Days and Electric Bills
- Heating bill correlates with heating degree days
- Growing Degree Days

Chapter 3 (cont)

- A way to determine if a crop can be successfully grown in any given area
- Assumes a BASE temperature for any given crop
- If daily mean is below the base, the plant goes dormant
- The difference between this BASE temperature and the daily mean temperature is a Growing Degree Day
- Some crops go dormant if daily mean is too high
- If daily mean > 86ºF, many plants stress out, go dormant
- In this event, the number of GDD is set at zero

Chapter 4

Water: A Unique Substance
Hydrogen Bonding
- The attractive force between H_2O molecules
- Hydrogen side of H_2O is “+” charged | Oxygen side is “-” charged
- + Hydrogen side attracted to oxygen side of other H_2O molecules
Formation of Ice
- When it’s cold, H_2O molecules cannot break their bonds
- Remain fixed in a crystalline structure, ice
- Lowest kinetic energy state
Liquid Water

Chapter 4 (cont)

- When it’s warmer, H_2O molecules break bonds temporarily
- Flow over each other but remain connected, liquid water
- Higher kinetic energy state
Water Vapor
- When it’s very warm, H_2O molecules break bonds completely
- Molecules scatter in random directions, gaseous water = water vapor
- Highest kinetic energy state
Ice-Water-Water Vapor
- When water absorbs or releases internal energy, it can change phase
Heat Energy
One calorie of heat energy is required to raise 1 gram of water 1ºC
Water: Changing Phases
- Latent Heat of Melting: 80 calories
- 80 calories of heat absorbed by 1g of ice melts into 1g of water
- No temperature change in the ice, but surrounding air gets colder
- Latent Heat of Fusion: 80 calories
- 80 calories of heat released by 1g of liquid water freezes to 1g of ice

Chapter 4 (cont)

- No temperature change in the water but surrounding air does heat up
- Latent Heat of Vaporization: between 540 and 600 calories
- 540 to 600 calories absorbed by 1g of liquid water evaporate to 1g water vapor
- Heat is taken from surrounding air resulting in decrease air temperature
- Latent Heat of Condensation: between 540 and 600 calories
- 540 to 600 calories released by 1g water vapor condenses to 1g liquid water
- Heat is added to the surrounding air resulting in a temperature increase
- Latent Heat of Sublimation: about 680 calories
- 680 calories of heat absorbed by 1g of ice to sublime to 1g of water vapor
- Heat removed from surrounding air greatly cools the air around the ice
- Latent Heat of Deposition: about 680 calories
- 680 calories of heat released by 1g of water vapor deposits to 1g of ice
- Heat added to the environment greatly warms the air around the ice

Chapter 4 (cont)

Measuring Water Vapor
- Mixing Ratio
- Mass of water vapor/mass of dry air it is in
- Water vapor measured in grams
- Dry air measured in kg
- Actual mass of water vapor in the air
- Saturation Mixing Ratio
- Max amount of water vapor allowed in the air (mostly determined by temperature)
- Vapor Pressure
- Pressure exerted by water vapor
- Total air pressure = sum of pressure from each gas
- The more water vapor in the air, the greater its contribution to the total air pressure
- Relative Humidity
- Mass of water vapor/mass of water vapor allowed to be in the air
- RH=mixing ratio/saturation mixing ratio
- RH=vapor pressure/saturation vapor pressure
- Relative humidity can be misleading
- Does not tell you how much water vapor is in the air unless you know the temperature of the air
- RH does tell you how close you are to saturating the air

Chapter 4 (cont)

- When air is saturated, condensation occurs
- The lower the RH, the faster water evaporates
- Watering lawn in the morning is more effective than watering in the afternoon
- RH can be over 100% but not for long (supersaturation)
- Violent updrafts in thunderstorms can supersaturate
- Dew Point Temperature (Td)
- Temperature at which saturation occurs
- Better way of measuring actual water vapor content
- Absolute Humidity
- Specific Humidity

Relationship Between T, Td, and RH
- When T and Td are close, RH is high
- When T and Td are far apart, RH is low

Water Vapor Rule
- Air can only hold so much water vapor
- When it has as much water vapor as physics allow, we say the air is saturated

Saturation Vapor Pressure
- Pressure exerted by water vapor when the air is saturated with it

Chapter 4 (cont)

- Amount of water vapor allowed in air is mostly determined by temperature
- Warmer temperatures allow for more water vapor

When Air is Saturated
Some kind of Condensation (Deposition) Occurs
- Dew forms
- Frost forms (if below freezing)
- Fog forms
- Cloud forms

Formation of Dew
Ideal Conditions
- Clear skies, light winds
- Allows for maximum radiational cooling of the ground
- Air in contact with ground cools to the dew point
- If air continues to cool below freezing, frozen dew occurs

Formation of Frost
When Deposition occurs instead of condensation

Clouds
Bringing Air to Saturation
- Cooling air is the easiest way to saturate the air
- Air always cools as it rises

Formation of Clouds
- Clouds result from condensation and/or deposition

Chapter 4 (cont)

- There usually needs to be condensation nuclei for it to form
- Dust, smoke, ash, salt, sulfate particles, and even bacteria
- Without these, clouds would not form and RH would need to be greater than 100% to form
- Deposition can occur in bitterly cold air without nuclei
- Condensation or deposition will always occur when RH reaches 100% (in this class)

Fog
- Cloud with base at the ground
- Forms when air temperature = dew temperature
- 4 types

1. Radiation
1. Ground cools rapidly and causes saturation near the ground
2. Nocturnal inversion can prevent higher fog
3. Clear skies, light winds, high relative humidity
4. Also called Valley frog
2. Advection
1. Warm, moist air blowing horizontally(advecting) over a “cold” surface
3. Upslope
1. Humid air moves up a hill or mountain

Chapter 4 (cont)

1. The upward flow causes the air to expand, cool, which can eventually reach 100%
4. Evaporative
- Process of Evaporation involved
- Rain falls, partially evaporates
- Adds water vapor to air, leads to saturation
- Evaporation also chills air, assiting in bringing air to saturation
- Precipitation Fog
- Steam Fog
- Cool dry air moves over warm surface, esp. water
- Common over lakes in autumn when lake is still warm from summer and air above it is cold and dry

Classification of Clouds
- Jean-Baptiste Lamarck (1802)
- Luke Howard (1803)
- Abercromby and Hildebrandsson (1887)

Clouds are classified by appearance, shape, and how high they are.

High Clouds
- Cirrus Clouds
- Composed mostly of ice crystals
- Thin due to limited water vapor
- Cirrocumulus
- Composed of mostly ice crystals but with lumps
- Cirrostratus

Chapter 4 (cont)

- Composed of mostly ice crystals and when thin, often causes a halo around sun/moon
- Can be thicker but usually, sun still partially shines through

Middle Clouds
- Altocumulus
- Mostly water droplets
- Darker regions noted
- Can signal the possibility of afternoon storms
- Altostratus
- Mostly water droplets with a “frosted glass” sun appearance
- Usually does not permit shadows to be cast

Low Clouds
- Stratus
- Layer of low clouds covering the sky
- Often seen after fog “lifts”
- Can have mist or drizzle
- Nimbostratus
- Light to moderate rain or snow
- Stratocumulus
- Lumpy clouds that appear in rows with some separation
- Lower than altocumulus with larger cloud elements

Clouds of Vertical Development
- Cumulus
- Cauliflower or cotton ball clouds

Chapter 4 (cont)

- Rising air below clouds, sinking air between clouds
- Cumulus Humilis
- Fair weather clouds
- Humble clouds that do not threaten to build into storms
- Cumulus Congestus
- May develop into thunderstorms
- Cumulonimbus
- Most intense rainmaker
- Overshooting top
- When the cloud punches through the stratosphere

Special Latin Descriptive Terms
- Cloud Varieties
- Uncinus
- Hooked shaped, often appear before stormy weather moves in
- Cirrus uncinus
- Fractus
- Stratus or cumulus clouds that appear broken
- Cumulus fractus better known as scud clouds
- Mammatus
- Udder-shaped protuberances often associated with the underside of a cumulonimbus anvil cloud
- Only cloud that forms in sinking air

Unusual Clouds
- Lentiular
- Lens-shaped and common over mountains and downwind of high terrain
- Pileus
- Cap clouds

Chapter 4 (cont)

- Form when moist air is pushed up under a develeoping cumulus cloud
- Banner Cloud
- Forms downwind of an isolated mountain peak
- Asperitas Clouds
- Often forming near precipitation-bearing clouds
- Undulating up and down like ocean waves

Super-high Clouds
- Nacreous
- Stratophere
- Noctilucent
- Mesosphere

Reminder: Rising air cools, temperature drops to dew point, condenses
- Excess water vapor condenses into tiny droplets
- Excess water vapor used up very quickly
- This results in Billions of teeny tiny water droplets whose radii are 20 microns or less

Observing Clouds from Spage
- Polar orbiting satellite
- Geostationary satellite
- Infrared imagery provides extra detail
- Darker shades of grey indicate warm clouds, thus low altitude
- Brighter grays and whites indicate cold clouds thus high altitude

Water Vapor Imagery

Chapter 4 (cont)

- Shows air motions (wind) even in cloud-free areas
- Detects water vapor at the 6.9μm wavelength
- Colorized to differentiate between dry and moist air
Two Main Types of Nuclei
- Condensation Nuclei
- Hygroscopic (water-seeking) nuclei
- Most effective condensation nuclei
- Salt crystals are the best
- Only RH ~75% required
- Hydrophobic (water-repelling) nuclei
- Least effective condensatioin nuclei
- Waxes and oil droplets discourage but do not totally prevent condensation
- RH must be 100% or even temporarily higher